Methane T-Dwarf Candidates in the Star Forming Region IC 348

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Abstract. IC 348 is a young (t~3Myr) and nearby (d~340pc) star forming region in the Perseus molecular cloud. We performed a deep imaging survey using the MEGACAM (z-band) and WIRCAM (JHK and narrowband CH_4 on/off) wide-field cameras on the Canada-France-Hawaii Telescope. From the analysis of the narrowband CH_4 on/off deep images, we report 4 T-dwarf candidates, of which 3 clearly lie within the limits of the IC 348 cluster. An upper limit on the extinction was estimated for each candidate from colour-magnitude diagrams, and found consistent with extinction maps of the cloud. Initial comparisons with T-dwarf spectral models suggest these candidates have a spectral type between T3 and T5, and perhaps later, potentially making these among the lowest mass isolated objects detected in a young star forming region so far.

INTRODUCTION

In the framework of the EU Marie Curie network "Constellation : the origin of stellar masses", we conducted a deep imaging survey of the star forming region IC 348 [5] with the aim to find isolated planetary mass objects, with a mass of a few M_{Jup}, and constrain the low mass end of the Initial Mass Function. Deep, wide-field broad-band zJHK and narrow-band CH4 on/off images were obtained at CFHT. Image analysis focused on faint source detection, and a number of photometric tests were conducted to ensure good photometric reliability and completeness down to K~19.5 mag.

SELECTION OF METHANE CANDIDATES

CH_4off (1.58μm) and CH_4on (1.69μm) narrowband filters were used to detect methane absorption bands that develop in the atmosphere of the coolest (T≤1200K) objects, the so-called T-dwarfs (cf. Fig. 1). We convolved observed low resolution spectra of field L1-T8 dwarfs with MEGACAM/WIRCAM filters in order to compute the expected CH_4on-CH_4off colours as a function of spectral type. The results are shown in Figure 1, with the L/T dwarf transition occurring at CH_4on-CH_4off≃0.1 mag for field dwarfs.

Stellar-like objects were detected on the deep CH_4off image and PSF photometry was applied to both the CH_4on and CH_4off images. In order to conservatively account for the photometric error, we selected T-dwarf candidates as having CH_4on–CH_4off ≥ 0.4 mag,

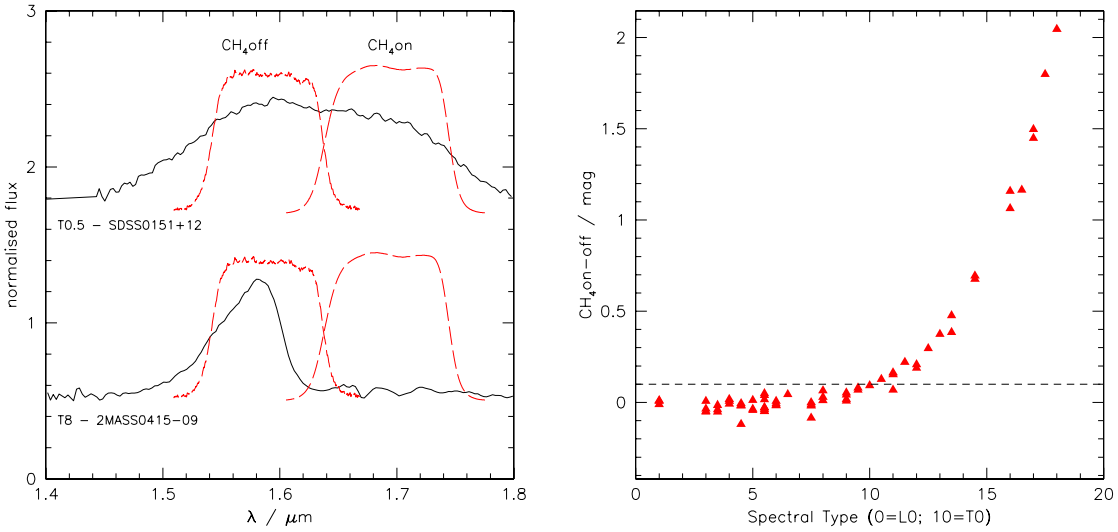

FIGURE 1. *Left :* Spectra of field T-dwarfs overlain by the WIRCAM CH_4 on/off filter transmission curves (dashed line). The CH_4on (1.69μm) filter is centered on the methane absorption band while the CH_4off (1.58μm) filter measures the nearby pseudo-continuum. T-dwarfs with deep methane absorption are expected to have larger CH_4on-CH_4off colours than non-methane dwarfs. *Right :* CFHT CH_4on-CH_4off synthetic colours versus spectral type for field L1-T8 dwarfs. The L/T transition occurs at CH_4on-CH_4off$\sim$0.1 mag for field dwarfs (dashed line).

which corresponds to a spectral type of about T3 or later (cf. Fig. 1). With this selection limit, 135 T-dwarf candidates were initially selected. Only 4 remained, however, after visual inspection of the candidates on the images, the other 131 being image artefacts (cross-talk, bad pixels, etc). The 4 T-dwarf candidates are shown in a CH_4on-CH_4off versus CH_4off diagram (Fig. 2), along with all the other stellar-like objects detected in the images. Cand-3589 remained undetected on the CH_4on image and has been plotted using the CH_4on detection limit ($\simeq$22.5 mag). The 4 candidates stand out in this diagram at 4σ or more above the rms photometric error (0.12 mag), as measured by the dispersion of the background population in the same magnitude bin.

PROPERTIES OF CANDIDATE T-DWARFS

An estimate of the extinction towards each candidate is required to derive their absolute magnitude and, using model isochrones, mass. An upper limit on the extinction was obtained from the J versus (J-H) diagram shown in Figure 2 by projecting the candidates back onto the COND isochrone. The results are summarised in Table 1 and concur with extinction maps of IC 348 by [4] and [6] which indicate $4 \leq A_V \leq 20$ mag for cloud members. Table 1 also lists the candidates magnitude and their spectral type estimated from Figure 2. Note, however, that the spectral classification is uncertain, as the comparison between IC 348 methane dwarfs and much older field T-dwarfs in Fig. 2 assumes that their widely different gravity does not impact on their methane colours.

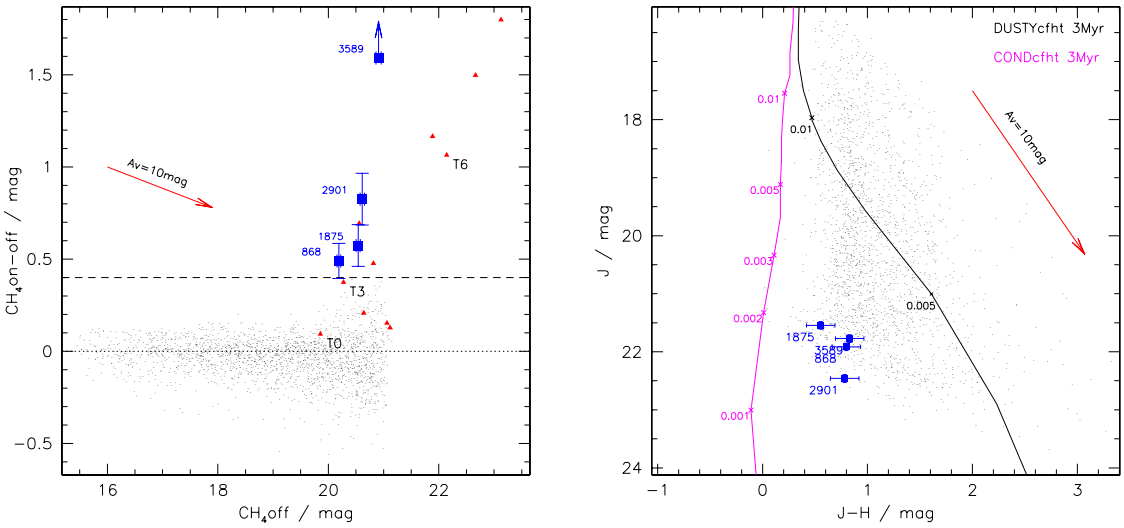

FIGURE 2. *Left :* Observed CH_4on-CH_4off colours versus CH_4off magnitude for stars in our survey. The 4 candidate T-dwarfs are shown as blue squares. The field T0-T7 dwarf sequence, shifted to a distance of 340 pc, is shown for reference (red triangles). At an age of 3 Myr, IC 348 T-dwarfs are expected to be brighter than field dwarfs, as are the 4 identified candidates. An extinction vector of A_V=10 mag is shown. Note the asymmetric distribution of the CH_4on-CH_4off colours in this diagram, with more field objects with negative values, due to extinction. *Right :* J versus (J-H) colour-magnitude diagram. Dusty (black) and Cond (magenta) 3 Myr isochrones are shown as solid lines labelled with mass ($M_\odot$). An A_V=10 mag extinction vector is shown. IC 348 T-dwarf candidates are shown as blue squares. They lie between Dusty and Cond isochrones as expected for intermediate T-dwarfs.

CLOUD MEMBERSHIP

The probability of one of the candidates being a foreground field T-dwarf projected against the cloud instead of being a bona fide IC 348 member can be estimated from the expected number density of T3-5.5 dwarfs in the solar neighourhood, ∼1 per 740 pc^{-3} [7]. The footprint of the CH_4 image is ∼0.11 deg^2, which at the distance of IC 348 (∼340pc) equates to less than one expected foreground T3-T5.5 dwarf in the corresponding volume. Background field T-dwarfs cannot contaminate our sample either as, at a distance of 340 pc or more, they would be at least 1 mag fainter than our candidates in the K-band, even neglecting extinction. Furthermore, 3 of our 4 candidates lie within 7′ of the cluster centre (cf. Table 1), the half-mass radius of which is 5′. We conclude that at least 3 of the 4 proposed T-dwarf candidates are probable IC 348 members, with a mass of a few jupiter masses according to theoretical models at an age of ∼3 Myr.

CONCLUSION

We report the detection of 4 methane dwarf candidates in the young star forming region IC 348. We tentatively estimate a spectral type in the range T3-T5 or even later, which would make these candidates amongst the least massive isolated objects ever detected in

TABLE 1. Photometry, estimated extinction (upper limit) and spectral type for the 4 T-dwarf candidates. The distance of each candidate from the cluster centre ($03^h44^m34^s$; $+32°09'48''$, J2000) is listed in the last column. When the candidate remained undetected in one filter, the magnitude listed is the detection limit, indicated with a '$*$'.

Object	z	J	H	K	CH_4off	CH_4on -CH_4off	A_V/mag	Sp.T.	Dist.
868	23.83	21.92	21.12	19.9	20.19	0.49	6.4	T3	13.4′
1875	23.30	21.55	20.99	20.14	20.54	0.57	4.2	T3.5	7.0′
2901	$\geq 26.2^*$	22.46	21.68	20.10	20.61	0.82	6.6	T4	4.1′
3589	25.22	21.77	20.94	20.26	20.91	$\geq 1.59^*$	6.6	$\geq$T6	1.5′

a star forming region. Although follow up observations are clearly needed, spectroscopic confirmation will be difficult owing to the faintness of the candidates.

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